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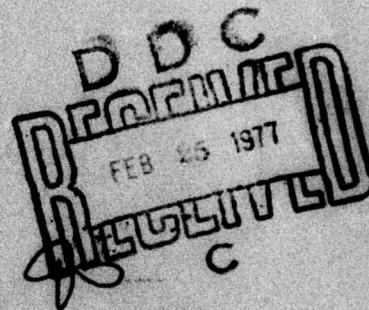
IONOSPHERIC RESEARCH USING SATELLITES

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30 December 1976

Final Report
1 Nov 1971 - 30 Sep 1976



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20. Abstract Amplitude scintillation records have been obtained of the 136 MHz beacon signal of the polar orbiting satellite NIMBUS 4. The records have been made at Marssarsuaq, Greenland, and cover the local time interval 22-02 of the auroral oval. The average behavior of scintillation versus zenith and azimuth is compared to a theoretical index deduced using weak scattering theory. The ionospheric irregularities are represented by a power law spectrum proportional to k^{-4} where k is the irregularity wave number. The comparison shows that the irregularities are elongated along the field lines with an elongation factor equal or greater than 2.5. Probably they are also elongated in the magnetic east-west direction with an elongation factor slightly greater than one. The night time scintillation corrected for geometric variation shows a marked increase when moving from sub-auroral to auroral oval latitudes.		
the inverse 4-th power of k , ↑ 400 798 600		

**Geometrical Considerations of 136 MHz Amplitude
Scintillation in the Auroral Oval**

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ABSTRACT.

Amplitude scintillation records have been obtained of the 136 MHz beacon signal of the polar orbiting satellite NIMBUS 4. The records have been made at Narssarssuaq, Greenland, and cover the local time interval 22-02 of the auroral oval. The average behaviour of scintillation versus zenith and azimuth is compared to a theoretical index deduced using weak scattering theory. The ionospheric irregularities are represented by a power law spectrum $\propto k^{-4}$, where k is the irregularity wave number. The comparison shows, that the irregularities are elongated along the field lines with an elongation factor ≥ 2.5 . Probably they are also elongated in the magnetic eastwest direction with an elongation factor slightly greater than one. The night time scintillation corrected for geometric variation shows a marked increase when moving from sub-auroral to auroral oval latitudes.

1. INTRODUCTION

Scintillation due to electron density fluctuations has been observed on line of sight paths in the ionosphere. The polar orbiting satellite NIMBUS 4 has been recorded for 136 MHz amplitude scintillation at Narssarssuaq, Greenland. The geographic coordinates of the station are 61.2°N and 45.4°W. The invariant latitude is 69°. The satellite is at a constant altitude of 1100 km. These data are unique because most other observations in the auroral zone of polar orbiting satellites have been made at lower frequencies and the recordings at 40 and 54 MHz frequently indicate strongly scattered signals. The weak scattering theory (BRIGGS and PARKIN, 1963), relating the scintillation to the ionospheric irregularities, to a high degree can be applied a large percentage of the time at 136 MHz. At 40 and 54 MHz strong, multiple scattering theory should be used, which is much more complicated.

The NIMBUS 4 records have been scaled manually to get the scintillation indices. All the night time data have been averaged to a statistical picture showing the zenith-angle and propagation-angle variation of the scintillation. This variation is compared to a theoretical formula as deduced from the weak scattering theory (COSTA and KELLEY, 1976).

In the deduction of this formula the ionospheric irregularities have been modeled by a power-law power spectrum, because recent in situ measurements (DYSON et al., 1974 ; PHELPS and SAGALYN, 1976) have shown this form of the power spectrum. Similarly ground based measurements of the scintillation power-spectrum (RUFENACH, 1972 ; SINGLETON, 1974 ; CRANE, 1976) indicate that the

irregularity spectrum follows a power-law.

2. THE NIMBUS-4 DATA

The NIMBUS-4 records have been scaled using the method outlined by WHITNEY et al. (1969). Before averaging the index is converted to the standard S_4 index. This has been done using a statistical relationship between the two indices as discussed by WHITNEY (1974). Only nighttime passes from the local time period 22-02 have been included. The hypothesis is, that around midnight the irregularities have a constant average intensity over a broad range of the auroral oval. Thus the main variation of the resulting scintillation should be caused by the geometry, which is expressed through the theoretical formula to be discussed later. Passes obtained during the period May-December 1972 have been used. No discrimination between different levels of magnetic activity has been made. This is primarily to get a large data base, but further has the advantage, that the latitudinal variation of irregularity strength is smoothed. The indices are averaged in boxes of 10° azimuth $\times 5^\circ$ zenith angle (Singleton, 1973). The variation of the average indices is illustrated in Figure 1. Data are missing northwest and east of the station because the low elevation passes have not been recorded. Notice that because of the sun-synchronous orbit the satellite is always moving from south to north during the night.

Four main features of the scintillation variation should be noted:

- 1) the high scintillation at large zenith angles.
- 2) the approximate symmetry around the magnetic meridian.
- 3) the north-south asymmetry of scintillation.

4) the ridge of enhanced scintillation slightly south of the station and extended in the magnetic east-west direction. These main features are to be expected from the geometry. The next step is therefore to make a quantitative comparison with the theoretical index. But first this index is discussed in the next section.

3. DISCUSSION OF THEORETICAL SCINTILLATION INDEX.

RUFENACH (1975) has described the mathematical evaluation of the theoretical scintillation index. When representing the ionospheric irregularities by a power-law power spectrum, he is not able to find a closed form for the scintillation index. However recently COSTA and KELLEY (1976) have shown, that this is possible. Combining their equations (4) and (5) the squared S_4 index is as follows:

$$S_4^2 = \sqrt{2\pi} (r_e \lambda)^2 \frac{\Delta N^2}{k_o} (L \sec i) \frac{a}{\beta} (1 - I_o) \left(\frac{\beta^2 - 1}{2\beta^2} x \right) \exp \left(-\frac{\beta^2 + 1}{2\beta^2} x \right) \quad (1)$$

r_e = classical electron radius = 2.8×10^{-15} m

λ = radio wave length = 2.2 m (136 MHz)

ΔN = variance (m^{-3}) of ionospheric irregularities.

$k_o = 2\pi/L_o (m^{-1})$, where L_o is the outer scale of the ionospheric irregularities.

$L \sec i$ = slant thickness of the irregularity layer.

i = zenith angle of radio ray at intersection with irregularity layer.

a = elongation of the irregularities along the magnetic field lines.

$$\beta^2 = \cos^2 \psi + a^2 \sin^2 \psi.$$

ψ = propagation angle = angle between the radio ray and the magnetic field direction.

I_0 = modified Bessel function of first kind and zero order.

$$x = 2 k_o^2 / k_f^2.$$

k_f^2 = squared Fresnel wave number = $4\pi/\lambda z$.

z = reduced slant range to irregularity layer = $z_1 (z_2 - z_1) / z_2$
where,

z_1 = slant range to irregularity layer,

z_2 = slant range to satellite.

Expression (1) depends upon the parameter, x . COSTA (private communication) has shown, that if $x \leq 0.15$ and $\beta > 0.5$, (1) may be substituted by the first order term in a series expansion of S_4^2 according to x . (The zero-order term is zero.

Thus S_4^2 reduces to:

$$S_4^2 = \frac{\pi}{\sqrt{2}} r_e^2 \lambda^3 \frac{(\Delta N)^2}{L_o} (L \sec i) z \frac{\alpha(1+\beta^2)}{\beta^3} \quad (2)$$

To estimate $x = \frac{2\pi\lambda z}{L_o^2}$ values of λ , z , and L_o are inserted. With NIMBUS 4, which is at a constant altitude of 1100 km and assuming a constant ~~altitude~~ of 350 km of the irregularity layer z is at most 966 km, when the satellite is at the horizon.

PHELPS and SAGALYN (1976) find that L_o is not smaller than 100 km in the altitude range 574-3523 km. Putting $L_o=10$ km as a lower estimate gives the value $x=0.13$ justifying the approximate formula (2).

Because of the Fresnel-diffraction, irregularities with sizes greater than the Fresnel zone $2\pi/k_f$ do not influence the scintillation. It is therefore surprising, that S_4 is proportional to ΔN , which is the total variance including the large size irregularities. However when a fractional variance is computed excluding all wave-numbers smaller than k_f , the square of this fractional variance is.

indeed proportional to $(\Delta N)^2 / L_0$ in agreement with (2).

S_4 is proportional to $\lambda^{3/2}$ as verified experimentally by CRANE (1976).

In the case the irregularities are elongated by a factor γ in the magnetic east-west direction, a $(1+\beta^2)/\beta^3$ should be replaced by
$$f(\psi, \phi) = \alpha\gamma(\gamma^2\cos^2\phi + \sin^2\phi + \cos^2\psi (\cos^2\phi + \gamma^2\sin^2\phi) + \alpha^2\sin^2\psi) / (\gamma^2\cos^2\psi + \alpha^2\sin^2\psi (\gamma^2 \cos^2\phi + \sin^2\phi))^{3/2} \quad (3)$$

where ϕ is the azimuth of the radio ray in a local coordinate system having z-axis along the magnetic field and y-axis in the magnetic east-west direction.

From (2) and (3) the geometric variation of S_4 is given by:

$$S_4 \propto \sqrt{z/\cos i} f(\psi, \phi) \quad (4)$$

$z/\cos i$ only depends upon zenith-angle. $f(\psi, \phi)$ depends both upon the zenith and azimuth angles through the two propagation angles ψ and ϕ .

Assuming a fixed ionospheric height of 350 km and using the constant height of 1100 km of NIMBUS 4, $z/\cos i$ increases by a factor 3.6 from zenith to the horizon. However this monotonic increase of $z/\cos i$ is partly cancelled by the variation of $f(\psi, \phi)$. If the elongation of the irregularities is larger along the field lines than perpendicular to the field lines $\alpha > \gamma$, $f(\psi, \phi)$ has an absolute maximum for $\psi=0$ and decreases monotonically for constant ψ , that is $\frac{\partial f}{\partial \psi} < 0$ for $\psi > 0$. $\psi=0$ means, that the radio ray propagates parallel to the earth's magnetic field. This happens when the satellite is southeast of the station and 13° from zenith (compare figure 1). Because ψ reaches larger values north of the station than to the south lower scintillation would be expected north of the station. However at large zenith angles $z/\cos i$ takes

over, such that a valley is created north of the station and a flat plateau south of the station.

The effect of introducing $\gamma > 1$ is to extend the maximum at $\psi = 0$ to a ridge, which is oriented in the direction of the perpendicular irregularity elongation.

This ridge may be misinterpreted as a latitudinal maximum of the irregularities themselves. This is analyzed in the final chapter where the relative variations of the experimental scintillation and expression (4) are compared.

4. COMPARISON WITH DATA

By changing the two elongation factors α and γ in equation (4) it is possible to model the relative variation of experimental scintillation (figure 1). However, the variance ΔN (equation 1) that is the irregularities themselves, may show some latitudinal dependence. To distinguish between this variation and the geometric variation, the latter is extracted from the experimental index (using (4)), and subsequently the corrected index is plotted versus invariant latitude. The positions of the invariant latitude circles are shown in figure 1. A fixed height of 350 km has been assumed. Figure 2 shows the latitude profile of the corrected indices after applying three sets of α , γ -values. To illustrate the scatter at a fixed latitude the upper and lower quartiles of the corrected indices are drawn. In the upper plot of figure 2 ($\alpha = \gamma = 1$) only the zenith-angle variation $\sqrt{z/\cos i}$ has been extracted ($f(\psi, \phi) = \text{constant}$, when $\alpha = \gamma = 1$).

The profile is symmetric around a large maximum at 68° - 69° invariant

latitude. This is not an expected latitudinal variation of the irregularity strength as explained in section two. Further the 68° - 69° latitude interval includes magnetic zenith ($\psi=0^{\circ}$), where the propagation angle factor f (equation 3) has its maximum. The profile is therefore identified with the propagation-angle variation. From equation (3) it may be seen, that the relative variation of f versus ψ and ϕ only changes little when α exceeds 2.5. Here γ is assumed to be close to unity. Therefore the upper plot of figure 2 can not be used to determine values of α , which exceed 2.5.

There is a cone around magnetic zenith, where the relative variation of S_4 depends upon α . However the resolution of the data in figure 1 is not good enough to analyse this cone.

Therefore the second plot of figure 2 gives a profile identical to profiles using larger values of α . It means the data should be interpreted as follows, that the irregularities are elongated along the field lines with an elongation factor $\alpha > 2.5$.

However even this plot ($\alpha = 2.5$, $\gamma = 1$) shows a narrow maximum at 68° - 69° , which is not likely due to a variation of ΔN .

In the lower plot ($\alpha = 2.5$, $\gamma = 1.3$) it is demonstrated, that it is partly possible to remove this narrow maximum by putting $\gamma = 1.3$. This means, that the irregularities are slightly elongated in the magnetic east-west direction. Using larger values of γ create unrealistic latitudinal profiles of scintillation. Notice, that the final profile ($\alpha = 2.5$, $\gamma = 1.3$) of which all the geometric variation has been extracted shows an increase of scintillation from 60° to 70° invariant latitude. This can only be interpreted as a variation of the irregularity strength (ΔN in equation 1) and is identified as moving from the scintillation boundary to the auroral

oval (AARONS, 1973). For convenience the relative variation of the geometric factor (4) with $\alpha = 2.5$, $\gamma = 1.3$ versus zenith and azimuth is shown in figure 3. The factor has been normalized to unity at zenith. This may be compared directly to the experimental data of figure 1.

5. CONCLUSIONS

The 136 MHz experimental scintillation data shows a relative variation versus zenith and azimuth which can be matched by the theoretical index (1) or the approximate expressions (2) - (3). Since these expressions have been deduced (COSTA and KELLEY, 1976) using a power-law ionospheric irregularity spectrum, this is further evidence, that the power-law spectrum is realistic also in the auroral oval. To get agreement it is necessary to assume, that the irregularities are elongated along the magnetic field lines by a factor greater than or equal to 2.5. There is also some indication, that the irregularities are elongated in the magnetic east-west direction, however at most by a factor 1.3. When all the possible geometric variation has been extracted, the scintillation in the local time interval 22-02 still shows an increase from 60° to 70° invariant latitude, which is identified as moving from polewards of the scintillation (or irregularity) boundary (AARONS, 1973).

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FIGURE CAPTIONS

Figure 1. 136 MHz S_4 scintillation indices from night time auroral oval plotted versus zenith- and azimuth-angle of the transmitting satellite. Blank areas mean no data. The invariant latitude circles 62° - 74° refer to a fixed ionospheric height of 350 km.

Figure 2. Experimental upper and lower quartiles of S_4 scintillation index corrected for geometrical variation and plotted versus invariant latitude. Three different sets of elongation-parameters α (along the field line) and γ (in the magnetic east-west direction) are used. To see the ability of the theoretical geometrical factor to match the relative variation of the experimental index a logarithmic scale is used.

Figure 3. Relative variation of the theoretical geometrical factor versus zenith and azimuth. The best fit values of the elongation parameters $\alpha = 2.5$ and $\gamma = 1.3$ have been used.

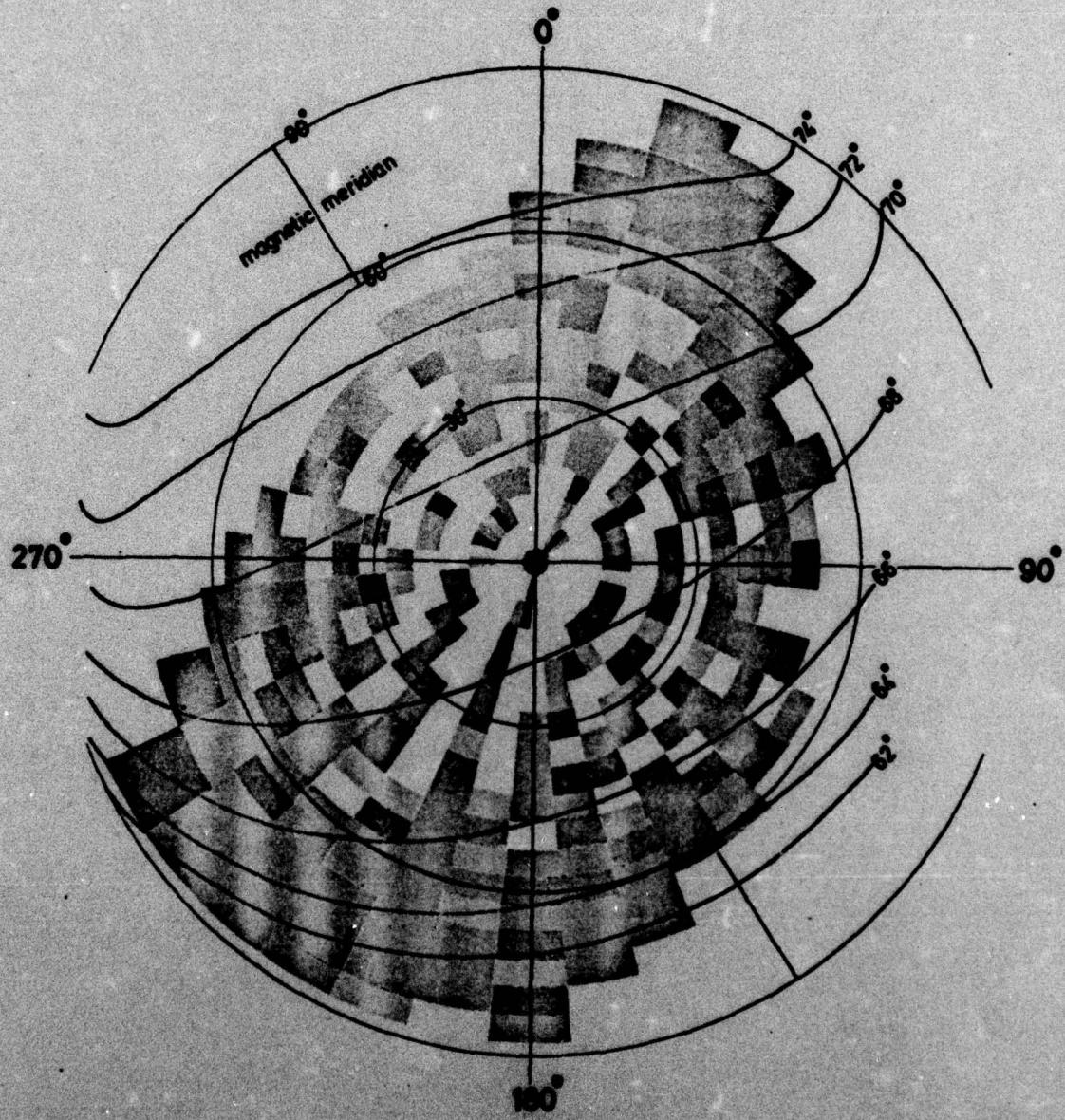


FIGURE 1

